

Investigating the variance of downwind spray deposits

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Summary

Spray applications in arable crops cause off-target spray deposits downwind from the treated field. Throughout several decades, many experiments have been carried out by many researchers to quantify these downwind spray deposits and their relation to sprayer settings, field conditions and environmental conditions. Still, there is a large variance in the observed data that cannot be explained satisfactorily by the experimental and environmental conditions. Variance in the data is most likely caused by sprayer boom movements and local fluctuations in driving speed, wind speed and wind direction. Experimentally quantifying the effects of such fluctuations on the variance in spray drift deposits is laborious and expensive. In this study variations in downwind spray deposits caused by sprayer boom movements are investigated based on simulations using the spray drift model IDEFICS. Realistic boom movements can easily result in coefficients of variation of tens of %.

Key words: Field trials, boom movements, spray deposits, variance, simulations

Introduction

Downwind spray deposits from field sprayers has been investigated for many years. Although many important factors are identified to understand averaged deposits, there is still a wide variation in both in-field and downwind spray deposits between individual experiments (e.g. Van de Zande *et al.*, 2006). Averaged environmental conditions and sprayer settings cannot explain such variation. The most likely parameters responsible for variation in spray deposits are horizontal and vertical boom movements and fluctuations in wind speed and wind direction. The effect of boom movements on in-field spray deposits has been investigated for many years (e.g. Speelman & Jansen, 1974; Nation, 1982; Langenakens *et al.*, 1999). In contrast, research on variations in downwind deposits of spray drift is rather limited. In fact, such variation has been studied only indirectly by investigating the effects of different static settings (e.g. De Jong *et al.*, 2000; Baetens *et al.*, 2007).

In this study, a quasi-dynamic model is described based on the IDEFICS spray drift model (Holterman *et al.*, 1997). The dynamic behaviour of boom movements and corresponding drift deposits is obtained from field measurements (Michielsen *et al.*, 2018). Fourier analysis of these measurements indicated the significant frequencies and amplitudes of the observed boom movements. Measured and modelled distributions of downwind deposits of spray drift are compared.

Materials & Methods

Quasi-dynamic simulations of spray drift using IDEFICS

The IDEFICS spray drift model can estimate downwind spray deposits for specified sprayer settings and environmental conditions (Holterman *et al.*, 1997). However, sprayer boom movements and local variations in for instance driving speed or environmental conditions is not foreseen. Typically, a full-field IDEFICS simulation run involves computing the flow paths through air of about 30,000 droplets per nozzle. In real time, this represents only a very short time scale (~ms). For input variables that vary on a much slower time scale, their effect may be simulated by a set of simulations representing static cases at appropriate time intervals with different conditions. The results of such simulations can be added, taking into account that the sprayer has moved forward between consecutive time steps. Each simulation is in fact static, while putting them together mimics a dynamic behaviour. This quasi-dynamic approach is used in the current study.

Measuring boom movements

In 2007 field measurements were carried out to quantify the variation of spray drift deposits alongside the edge of a potato field (Michielsen *et al.*, 2018). Deposits of spray drift were measured at the crop-free edges surrounding the field. The sprayer used was a 24 m wide Hardi Commander (Twin Force), driving at 6.0 km h^{-1} (1.7 m s^{-1}) (see Fig. 1). Horizontal boom movements were measured using a laser distance indicator (DME200; Sick BV, The Netherlands); measuring frequency ca. 200 Hz. Boom height was measured using an ultrasonic device (P42-A4N-2D-1C1-13; PIL Sensoren GmbH, Germany); measuring frequency ca. 48 Hz. The ultrasonic device was connected to the tip of the boom and measured the height above the bare soil strip next to the potato field. The soil strip was flattened to obtain accurate height readings.



Fig. 1. Tractor and Hardi Commander sprayer driving through potato field, parallel to a bare soil field. Filter strips parallel to the field edge allow measuring variation in deposits along the edge.

After subtracting the constant driving speed, the horizontal deviations from a straight line are obtained. Fig. 2a shows an example of a single run. Occasionally, the deviation appears to be more than 1 m, but typically the deviations are $<0.5 \text{ m}$. The pattern shows that the boom appears to

move in a few significant frequencies. Although the time series is relatively short, a Fourier analysis may indicate which frequencies are important. The spectrogram (Fig. 2b) is not very accurate, but clearly shows that the important frequencies are all less than about 0.5 Hz. The smoothed red line indicates that roughly three frequencies seem to dominate, at approximately 0.05 Hz, 0.25 Hz and 0.5 Hz. The standard deviation (SD) of the horizontal deviations is about 0.31 m.

The ultrasonic device measured the height of the boom tip above ground level. The deviations from average height (0.83 m) are shown in Fig. 3a, representing the same measurement as in Fig. 2. The Fourier transform of this data series is shown in Fig. 3b. The most prominent frequency is about 0.05–0.1 Hz; higher frequencies are only weakly present. As the soil surface is not completely flat, the measured signal is disturbed by the unevenness of the soil surface. SD of the height fluctuations is about 0.13 m.

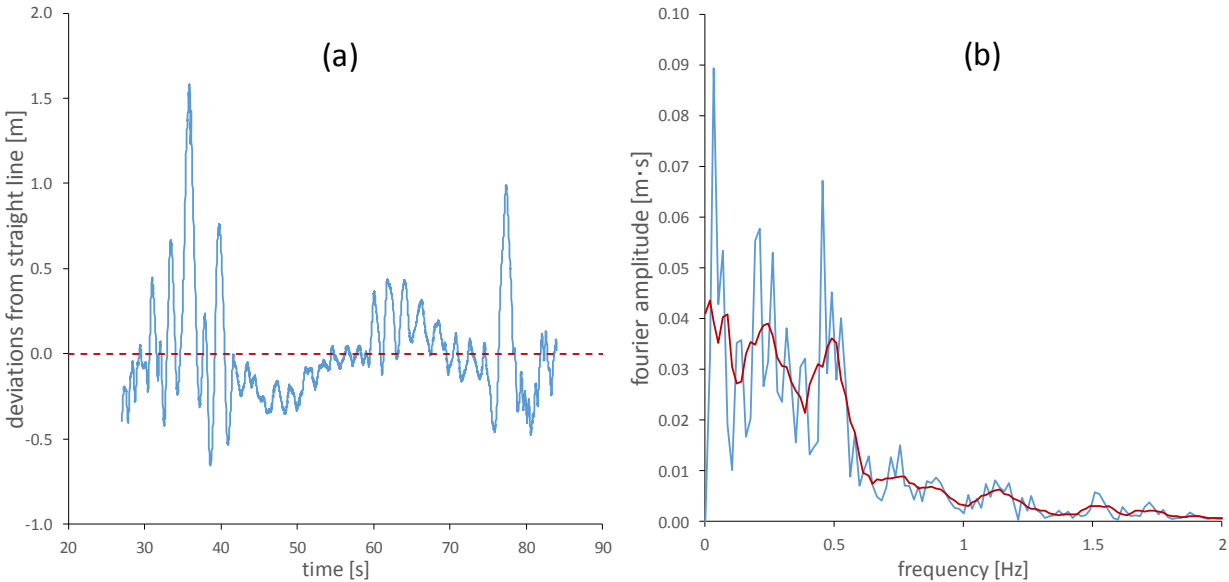


Fig. 2. Horizontal boom movements; (a) measured horizontal deviations of the boom tip of a sprayer driving at constant speed through a field. (b) corresponding Fourier frequency plot; the red line shows a smoothed pattern.

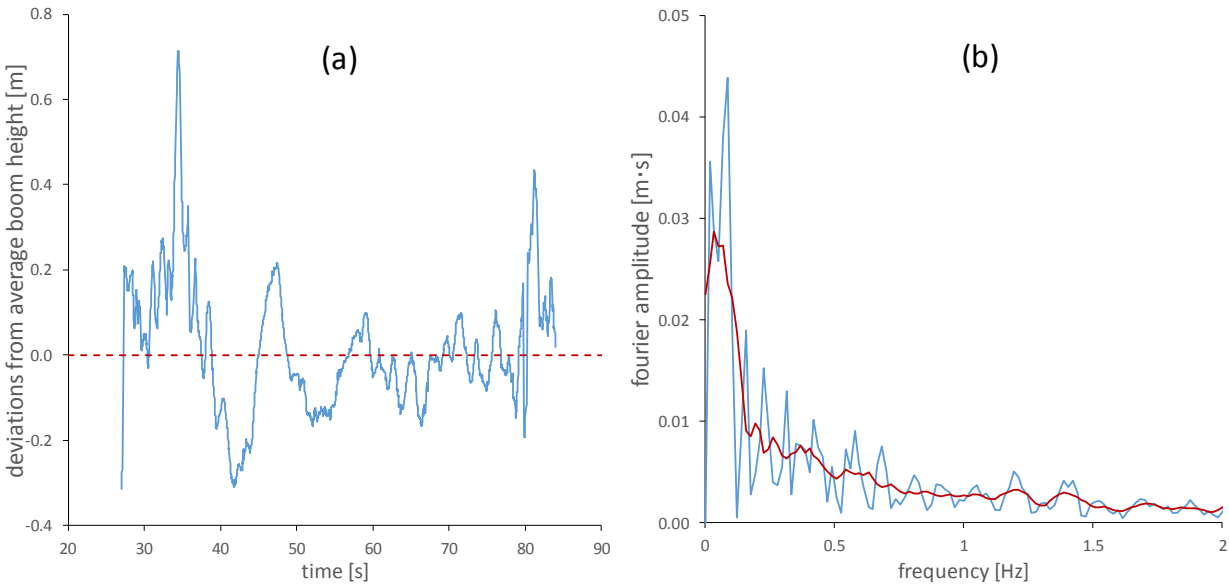


Fig. 3. Vertical boom movements; (a) measured vertical deviations of the boom tip of a sprayer driving at constant speed through a field. (b) corresponding Fourier frequency plot; the red line shows a smoothed pattern.

The accuracy of boom height measurements depends on the flatness of the bare soil next to the potato crop. Assuming the unevenness of the soil surface is due to soil clumps with size of about 0.1 m. At a forward speed of $1.7 \text{ m}\cdot\text{s}^{-1}$ this would yield a frequency of about 17 Hz in the Fourier spectrogram. This is far above the frequencies caused by boom movements (Fig. 3b) and therefore soil unevenness will probably cause no problems in investigating vertical boom movements.

Fig. 4a shows the same Fourier spectrum as in Fig. 3b, but now up to 20 Hz. Though not very clear, the presence of frequencies between 10 and 12 Hz seems slightly enhanced and maybe also between 18 and 20 Hz. These frequencies would correspond to periodic unevenness of the soil surface of 0.15 and 0.09 m, respectively. Assuming frequencies >5 Hz are not caused by boom movements, a reconstruction pattern of boom height for all these frequencies would represent soil unevenness. The red line in

Fig. 4b shows this reconstruction and indicates that the soil surface in this experiment was relatively flat, except for about the first and last 10 s of the track. SD of this reconstructed height is 0.013 m. SD of the flat central part (37–77 s) is only 0.003 m.

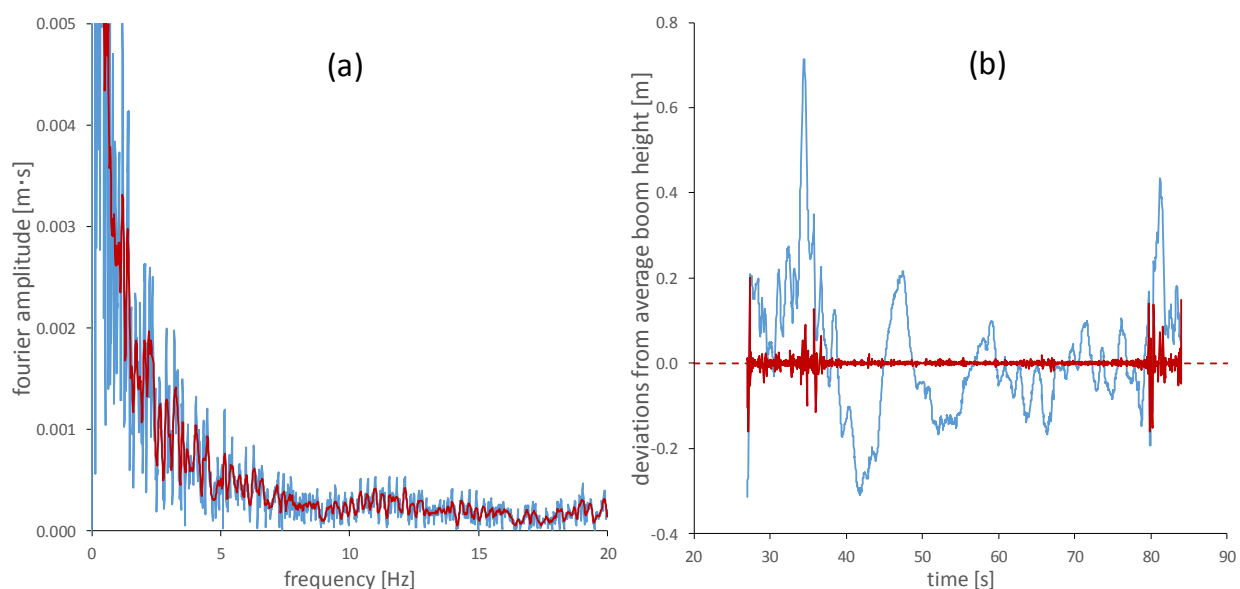


Fig. 4. Vertical boom movements; higher frequencies; (a) Fourier amplitudes up to 20 Hz; red line: smoothed curve; (b) blue: measured boom height deviation; red: reconstructed boom movements for frequencies >5 Hz only.

Simulated boom movements

Assuming sinusoidal horizontal fluctuations of the sprayer boom of frequency f and amplitude a , it can easily be shown that SD of such a fluctuation equals $a/\sqrt{2}$. In the previous section, measurements indicated $\text{SD} \approx 0.31 \text{ m}$ for horizontal movements. Consequently, if this SD would be caused by a single sinusoidal wave, the required amplitude would be $\text{SD} \cdot \sqrt{2} \approx 0.44 \text{ m}$.

Simulations using the IDEFICS spray drift model were carried out to mimic the measurement described in the previous section. In the simulations, a conventional boom sprayer was supplied with Teejet XR11004 nozzles, liquid pressure 300 kPa. Crop height was 0.50 m; boom height 0.35 m above the crop, forward speed $1.67 \text{ m}\cdot\text{s}^{-1}$, cross wind $3.5 \text{ m}\cdot\text{s}^{-1}$ (at 2 m height). Similar simulations were carried out for boom heights 0.05 through 0.65 m above the crop, in steps of 0.05 m. 2D static patterns (resolution $0.1 \times 0.1 \text{ m}^2$) for these simulations formed the basis of the quasi-dynamic simulations of boom movements.

For simulations of boom movements in the horizontal plain, the static deposition pattern at boom height 0.35 m above the crop was used. An overlay of a large number of this pattern was formed for a range of sprayer boom positions determined by the average forward speed of $1.67 \text{ m}\cdot\text{s}^{-1}$ and

sinusoidal fluctuations in horizontal displacements given by frequency of 0.50 Hz or 0.25 Hz, and amplitude 0.44 m.

For simulations of vertical boom movements, the set of 13 static deposition patterns was used, representing boom heights 0.05 m through 0.65 m above the crop, in steps of 0.05 m. Quasi-dynamic behaviour was simulated for an average forward speed of $1.67 \text{ m}\cdot\text{s}^{-1}$ and average boom height of 0.35 m above the crop. Sinusoidal height variation was assumed at a frequency of 0.1 Hz and amplitude 0.18 m, being a factor $\sqrt{2}$ larger than SD of 0.13 m as observed in measurements described above. For heights in between those of the 13 predefined patterns linear interpolation was applied to estimate appropriate deposition patterns.

Results

The simulations involving horizontal boom movements resulted in spray deposition patterns as shown in

Fig. 5a and

Fig. 5b for $f=0.50 \text{ Hz}$ and $f=0.25 \text{ Hz}$, respectively. The higher frequency causes larger differences in spray deposits than the lower frequency: the peaks are higher and the troughs in between are lower. For both frequencies, these differences decrease for increasing downwind distance (Fig. 6a). Similarly, the coefficient of variation along the field edge decreases with increasing downwind distance (Fig. 6b). At about 2 m downwind, CV is almost 50% and almost 30% for frequencies 0.50 Hz and 0.25 Hz, respectively. At 5 m downwind, CV has decreased to 37% and 27%, for $f=0.50 \text{ Hz}$ and $f=0.25 \text{ Hz}$, respectively.

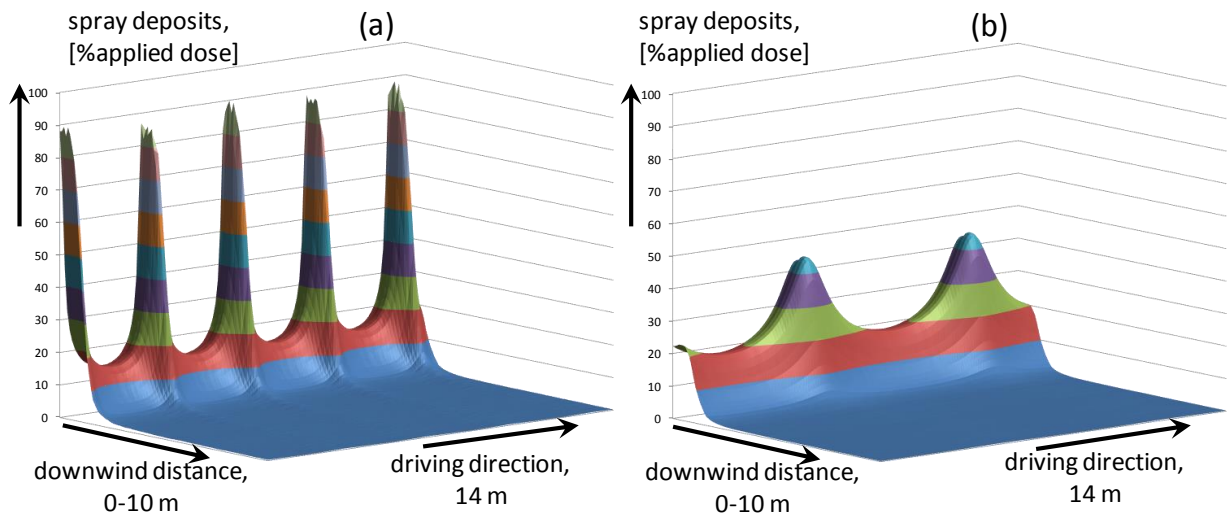


Fig. 5. Distributions of downwind spray deposits with horizontal boom movements, driving speed $1.7 \text{ m}\cdot\text{s}^{-1}$; (a) $f=0.50 \text{ Hz}$, $a=0.44 \text{ m}$ (b) $f=0.25 \text{ Hz}$, $a=0.44 \text{ m}$.

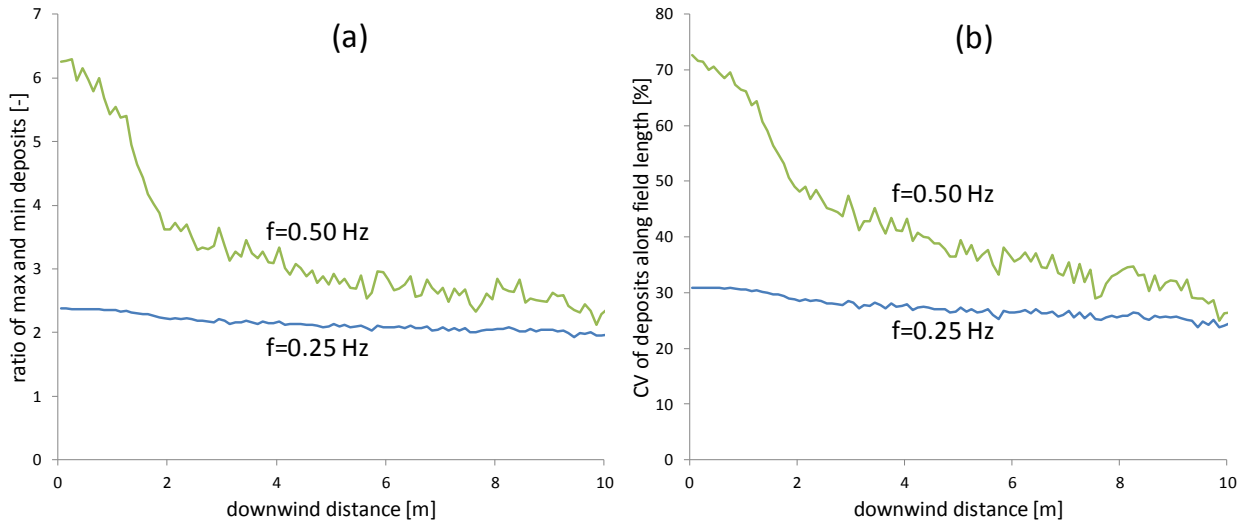


Fig. 6. Simulation with horizontal boom movements; green curves: $f=0.50$ Hz, blue curves: $f=0.25$ Hz; (a) ratio of max and min deposits along the field edge, as a function of downwind distance; (b) CV of spray deposits along the field edge, as a function of downwind distance.

The simulations for vertical boom movements were carried out with settings given in the previous section. Sinusoidal vertical movements were assumed of frequency $f=0.10$ Hz and amplitude $a=0.18$ m, corresponding to the experimental results described above. The 2D deposition pattern from the simulation is shown in Fig. 7a. Since the frequency of 0.1 Hz is very low, the periodic behaviour along the length of the field is slow. In this case the periodic repetition in driving direction is about 17 m. Still, deposits at a given downwind distance may vary considerably. Fig. 7b shows CV and ratio of maximum and minimum deposits as a function of downwind distance. At about 1.7 m downwind $CV=65\%$ and max/min ratio is almost 8.

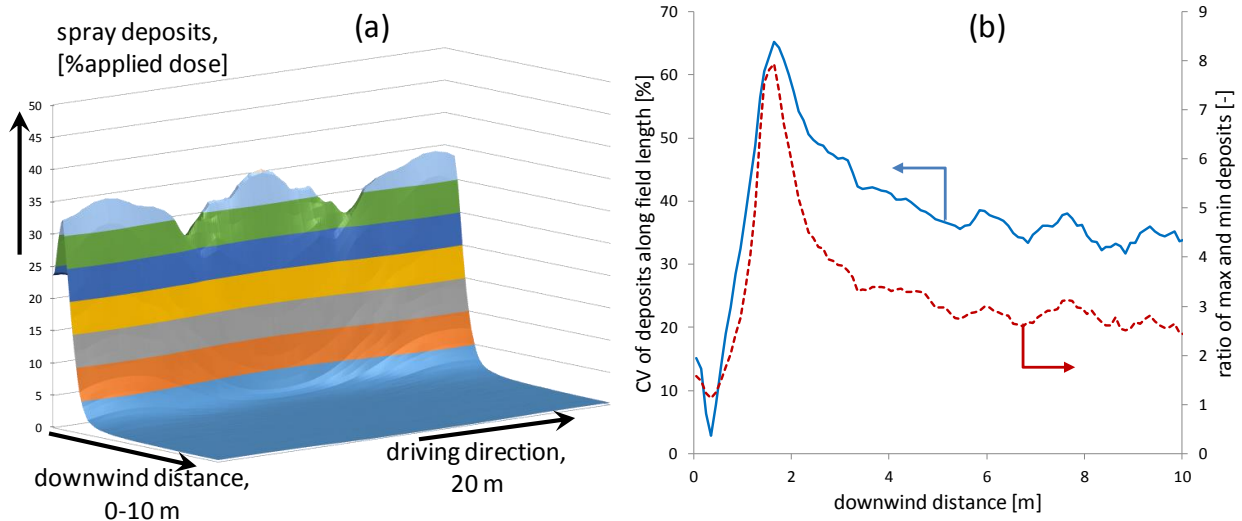


Fig. 7. Simulations with vertical boom movements, driving speed $1.7 \text{ m}\cdot\text{s}^{-1}$, average boom height 0.85 m , $f=0.10$ Hz; $a=0.18 \text{ m}$; (a) distribution of downwind spray deposits (b) corresponding CV (blue solid curve) and max/min ratio (red dashed curve) as function of downwind distance.

Discussion

Using an appropriate set of static patterns of downwind deposits of spray drift, the quasi-dynamic effects of boom movements on such deposits can be mimicked. The results fairly agree with measured variations. There are some important limitations, though, that will be discussed below.

Measured spray deposits at 2 m downwind along the length of a potato field showed a coefficient of variation (CV) of about 50% at the central part of the track (Michielsen *et al.*, 2018). Similarly, at 5 m downwind CV was about 30% along the field length. Simulations of horizontal and vertical boom movements at frequencies and amplitudes equivalent to those observed in the measurements yielded CVs in the same order of magnitude. The simulations involved either horizontal or vertical movements. Combined movements were not simulated yet. Differences in frequencies and phase of periodic horizontal and vertical boom movements may lead to both enhanced and decreased variations.

The accuracy of boom height measurements depends on the flatness of the bare soil next to the potato crop. Assuming higher frequencies (>5 Hz) in the corresponding Fourier spectrogram are caused by unevenness of the soil surface, this unevenness can be quantified by a Fourier reconstruction. In the experiment presented here, the reconstruction shows that the soil strip was sufficiently flat to have no effect on low-frequency height deviations caused by vertical boom movements. The first and last part of the track showed an increased height deviation by higher frequencies (

Fig. 4b). This is caused by increased boom movements when the tractor and sprayer drive through the head lands at both ends. Apparently, higher frequencies do occur in the boom movements and cannot be assigned to soil unevenness only. Consequently, the assumed boundary frequency of 5 Hz for soil unevenness is arbitrary.

The current setup of the quasi-dynamic simulation model is limited to translational boom movements only. Pivoted boom movements like yaw and roll require a different approach where a set of static situations may not be sufficient. Frequencies and amplitudes of boom movements depend on the dynamics of the boom suspension system and may differ from the values presented in this study. Besides, in the current study only one experiment of a set of repeated experiments was used. Clearly, simple sinusoidal movements are far from reality. Investigating simultaneously horizontal and vertical boom movements in multi-frequency mode would be a significant step forward.

The IDEFICS spray drift model simulates turbulence in a random way. The gusty nature of real wind is not modelled accurately this way. Thus, the effects of gusts of wind on variation of downwind spray deposits cannot be simulated by IDEFICS directly. The quasi-dynamic approach is insufficient to mimic gusts, as in each of the underlying static cases wind direction is fixed for the drifting spray cloud. To model gusts of wind at least a 2D approach of the wind field for the whole crop area and relevant downwind area is required. This 2D wind field should be time-dependent as well, at least representing the time the drifting spray cloud needs to reach the downwind area of interest. Clearly, such an approach is much more difficult than the quasi-dynamic model presented in this paper.

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